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Computer-Aided Design of Active Packaging/Food System for extended shelf life

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MOTIVATION

Common dynamic models of active packaging are focused on the mass transfer of the antimicrobial agents. Nevertheless, the interaction of the antimicrobial agent with the food microorganisms is usually neglected, despite being critical to optimise the food safety and quality.

OUTLINE

In this work, we propose a dynamic model simulating the dynamics of carvacrol and its inhibition by *Listeria monocytogenes* in an active packaging system. Carvacrol is an antimicrobial agent in oregano allowed as a food additive and *Listeria monocytogenes* is the major psychrotrophic pathogen in food. The model can be exploited to study different aspects of the food quality and safety, such for example the maximum load of Listeria before packaging and the concentration of carvacrol to guarantee food quality and safety standards.

Modelling the active packaging system

Carvacrol in the polypropylene

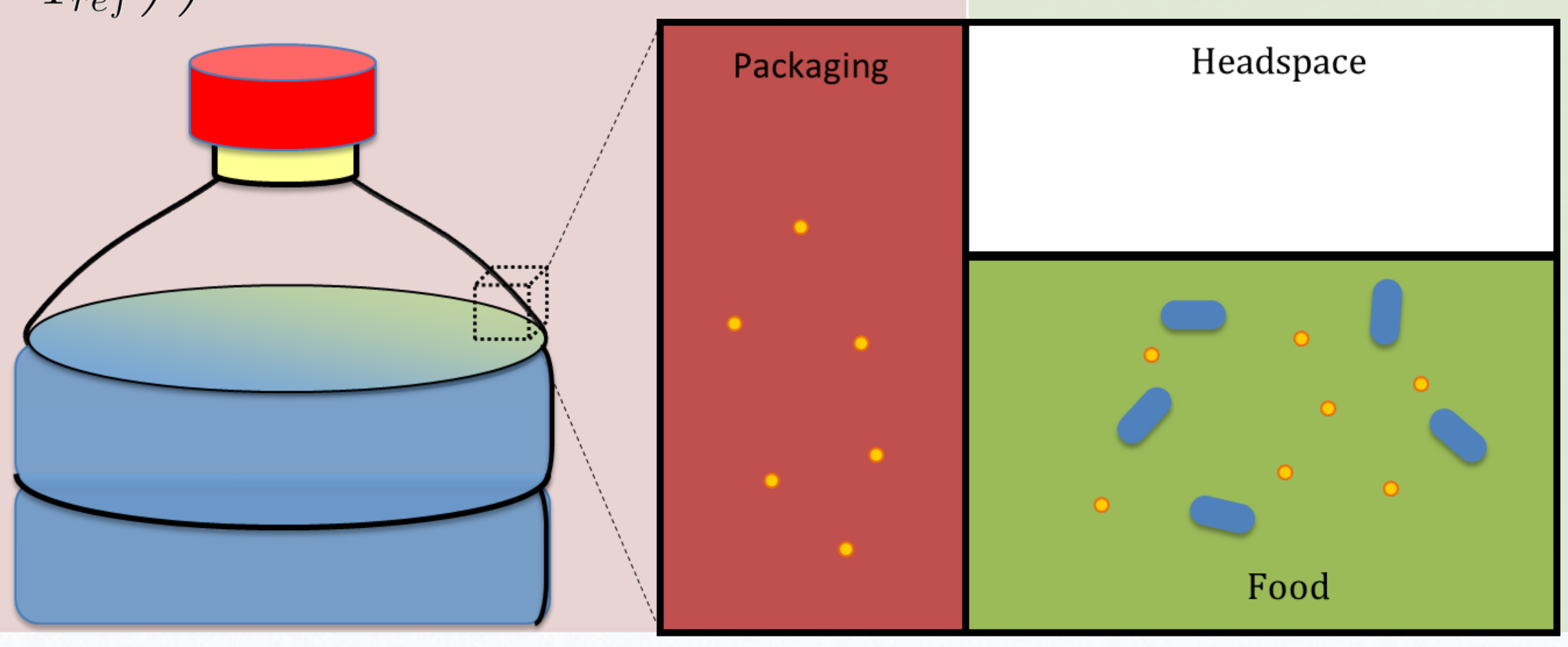
$$\frac{\partial C_{PP}}{\partial t} = D\frac{\partial^2 C_{PP}}{\partial x^2} \quad \text{for } t>0 \text{ and } 0<x<H$$

Boundary and initial conditions

$$\begin{cases} C_{PP}(x,0) = C_{pack,0} \\ \left.\dfrac{dC_{PP}}{dx}\right|_{(0,t)} = 0 \\ D\left.\dfrac{dC_{PP}}{dx}\right|_{(H,t)} = k_L\, a(C_L^*(t) - C_{PP}|_{(H,t)}) \end{cases}$$

Diffusivity changes with temperature

$$D(T) = D(T_{ref})\exp\left(-\frac{E_A}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right)$$



Carvacrol (antimicrobial substance)
Listeria (pathogen)

Modelling the food system

Carvacrol in the food matrix

$$\frac{dC}{dt} = -k_L a(C^*(t) - C_{PP}|_{(H,t)})$$

$$C^* = CK$$

$$K = \frac{C_{PP}^\infty}{C^\infty}$$

Listeria (pathogen) in the food matrix

$$\frac{dy(t)}{dt} = \mu = \mu_{opt}\gamma_T\gamma_C$$

Growth depends on temperature

$$\gamma_T = \frac{(T-T_-)(T-T_-)^2}{(T_*-T_-)[(T_*-T_-)(T-T_*)-(T_*-T_+)(T_*+T_--2T)]}$$

Growth is inhibited by carvacrol concentration

$$\gamma_C = \begin{cases} \left(1-\frac{C}{MIC}\right)^2, & C<MIC \\ 0 & C \geq MIC \end{cases}$$

Optimal design of the active packaging/food system

MAXIMUM LIMITS OF Listeria BEFORE PACKAGING

$$\max_{y(t_0)} \quad y(t_0)^2$$
$$\text{s.t.} \quad y(t_f) < 2$$

Find maximum levels of *listeria* before packaging subject to

- **Restriction at final time for *Listeria.*** EFSA established that the maximum concentration of *Listeria monocytogenes* cannot exceed 100 cfu/g during the product shelf-life. Let us assume that 1 gram of food approximates 1 millilitre. Therefore, per any millilitre of product juice the numbers of viable cells have to be less than 100 viable (y=log10(100)=2) cells

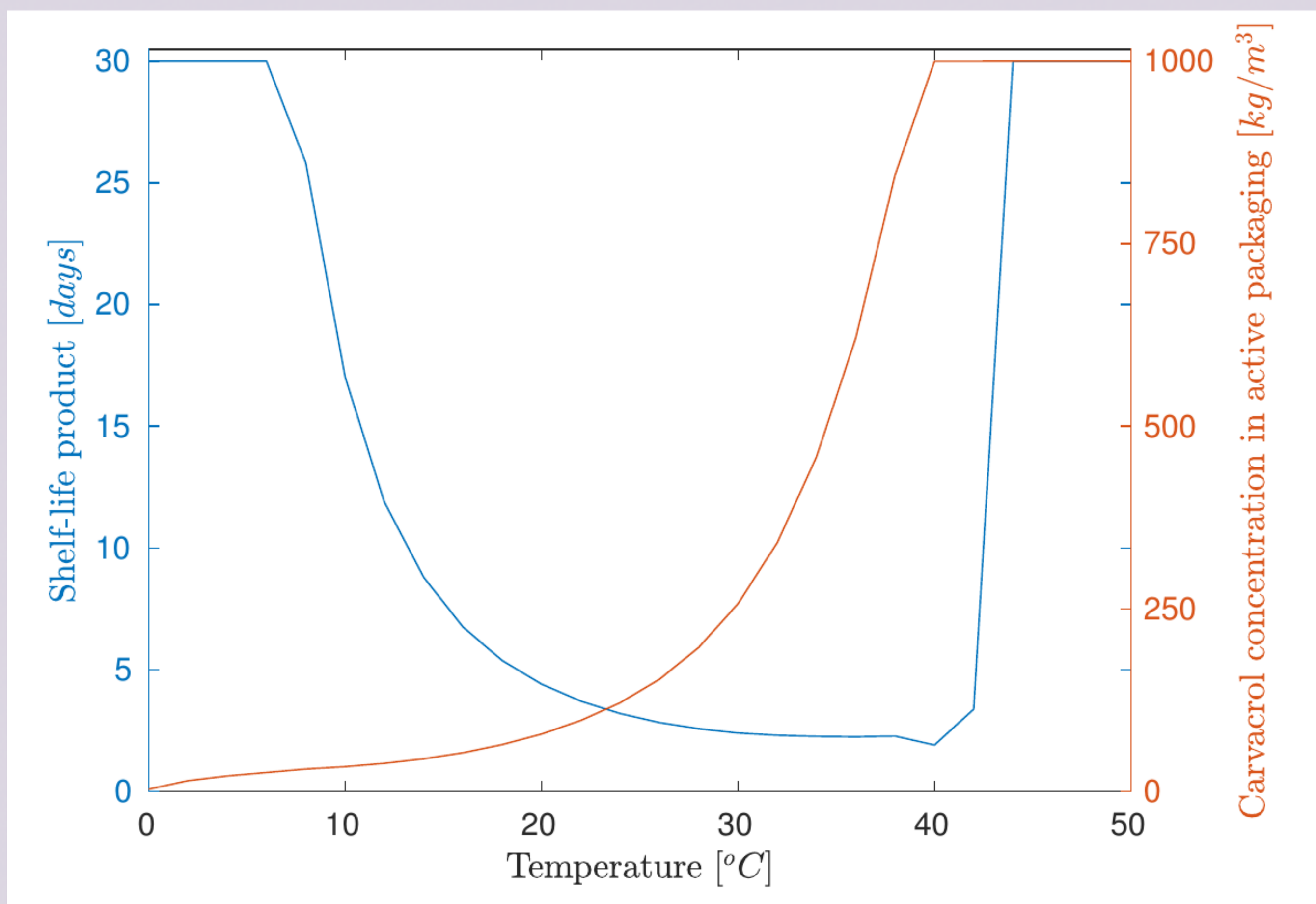
Conditions			Limit
Shelf-life	$C[Kg/m^3]$	$T[^\circ C]$	$10^{y(t_0)}[cfu/ml]$
3 days	0	-1	71.71
5 days	0	-1	57.45
10 days	0	-1	33.00
3 days	0	5	0
5 days	0	5	0
10 days	0	5	0
3 days	50	5	88.37
5 days	50	5	88.12
10 days	50	5	87.66

OPTIMAL DESIGN TO MAXIMIZE SHELF-LIFE SATISFYING FOOD QUALITY AND SAFETY SPECIFICATIONS.

$$\max_{t_f, C_{pack,0}} \quad t_f^2$$
$$\text{s.t.} \quad y(t_f) < 2$$
$$C(t_f) < 0.3$$

Find final product time (Shelf-life tf) and carvacrol required to maximize shelf-life subject to:

- **Restriction at final time for *Listeria.***
- **Restriction at final time for carvacrol** to avoid strong pungent, warm odour characteristic of oregano



CONCLUSION:

We propose a model to simulate an active packaging where *Listeria monocytogenes* is inhibited with carvacrol at non-isothermal conditions.

We design two optimisation problems that illustrate the relevance of this type of models: maximum concentration of Listeria allowed during packaging to meet the EFSA recommendations and carvacrol in the active packaging to maximising shelf-life of the product at different temperatures.

The approach also allows considering time-varying profiles of temperature to simulate different expected storage conditions along the food chain.

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RESISTANCE

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